# A Channel Model for VANET Simulation System

Liming Zhang[1], Feng Chen[*2]

Department of Automation, University of Science and Technology of China

Hefei, Anhui, China

[1]zlm0913@mail.ustc.edu.cn; [*2]chenfeng@ustc.edu.cn

***Abstract***

Vehicular Ad Hoc Network (VANET) is the key technology of Vehicle Infrastructure Integration (VII). Microscopic simulation is an effective means for VANET research, and radio channel model is the basis of VANET simulation. In this paper, radio wave propagation models, such as reflection and diffraction models, are combined to develop a VANET channel model, and the model is introduced into VANET simulation system. Path loss and received power under different traffic flow are analysed using our VANET simulation system. The simulation results are consistent with the real situations of Vehicle-to-Vehicle (V2V) communication.

***Keywords***

*Vehicular Ad Hoc Network; Simulation; Channel Model; Path Loss; Received Power*

## Introduction

VANET is the development trend of Intelligent Transportation System (ITS). It can significantly improve the traffic in safety, efficiency and information service. VANET has received considerable attention in recent years. The standard of Dedicated Short Range Communications (DSRC) has been established. Federal Communications Commission has extended IEEE 802.11 Standard for VANET. This extended standard is called IEEE 802.11p, which is authorized to work in 5.9GHz free band. It is highly difficult to study VANET by field experiments due to its complexity. Traffic simulation can describe temporal and space behaviours of vehicles in micro-level with low cost, so it becomes an effective means for the research of VANET.

Channel model is the basis of VANET simulation. VANET channel is affected by multiple factors including the buildings, road situations, vehicle type, and vehicle relative velocity. The related works are as follows: A VANET channel is modelled using optical ray tracking technique by Maurer. This kind of model is usually in good agreement with the real world, but implemented with high computational complexity. A widely used simplified stochastic model is employed to fit to real-world measurements by Turkka and Paschalidis. This kind of model offers approximation of VANET channel at low computational cost, but is not suitable for typical scenarios. In order to simulate the VANET channel in typical scenarios, many researchers consider buildings as obstacles, especially at the intersection. However, the impact of vehicles as obstacles on V2V communication has been largely neglected in VANET research. Boban emphasized the importance of considering other vehicles on the road as obstacles, and presented a method to analyse the existence of the Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS).

In this paper, the vehicles between transmitter and receiver are considered as obstacles. By combining several radio wave propagation models, we propose a VANET channel model which is easy to implement and suitable for specific traffic scenarios, and apply the model into VANET simulation system.

The paper is organized as follows. In Section 2, path loss and radio wave propagation models are introduced. In Section 3, the VANET channel model is developed, and the simulation procedure is described. In Section 4, the simulation results are analysed. Finally, the conclusions are drawn in Section 5.

## Related Theories

Radio waves may encounter many obstacles while propagating from transmitter to receiver. This will lead to reflection, diffraction and scattering of radio wave. Both large-scale propagation effect and small-scale propagation effect will occur when radio waves propagate. Large-scale propagation effect is used to describe the variations of field strength received over relatively long distances, in which path loss and shadowing are mainly considered. Small-scale

propagation effect is used to describe the variations of field strength received over very short distances, in which multi-path delay and Doppler shift are mainly considered.

The concept of path loss plays a vital role in describing the attenuation of signal power. In VANET simulation, to calculate the received power, we consider the path loss in several radio wave propagation models.

### *Path Loss*

Path loss is defined as

$$PL[dB] = 10\log_{10}\frac{P_t}{P_r} \qquad (1)$$

where, $P_t$ is the transmitted power; $P_r$ is the received power.

According to the theory and measurements, received power attenuates with the logarithm of propagation distance, which can be expressed as Log-Distance Power Law (LDPL):

$$PL[dB] = PL(d_0) + 10n\log(\frac{d}{d_0}) \qquad (2)$$

where, $n$ is the path loss exponent, to describe how quickly the signal power attenuates; $d$ is the distance between Transmitter and Receiver (T-R); $d_0$ is the reference distance determined by measurements. The value of $n$ depends on the propagation environment. In free space, $n = 2$, otherwise, $n > 2$.

The statistical model can be used when there are obstacles with unknown sizes and locations between T-R. The most widely used statistical model is Log-Distance Shadowing Model:

$$PL[dB] = PL(d_0) + 10n\log(\frac{d}{d_0}) + X_\delta \qquad (3)$$

where, $X_\delta$ is a normally distributed random variable with mean 0 and standard deviation $\delta$, describing the shadowing effect caused by obstacles. The value of $n$ and $\delta$ can be obtained by linear regression of the measurement data.

### *Radio Wave Propagation Models*

The following are several radio wave propagation models including free space model, two-ray ground model, single knife-edge diffraction model and multiple knife-edges diffraction model. We address the path loss for all of these models.

#### *1) Free Space Model*

Free space model is used when there is no obstacle between T-R, and the radio wave propagates along a straight line.

The received power at distance $d$ from transmitter is

$$P_r = P_t\frac{G_l\lambda^2}{(4\pi)^2 d^2} \qquad (4)$$

where, $P_t$ is the transmitted power; $P_r$ is the received power; $G_l = G_1G_2$ is the product of transmitting antenna gain and receiving antenna gain; $d$ is the T-R distance; $\lambda$ is the wavelength.

The path loss of free space model is

$$PL[dB] = -20\log_{10}\frac{\sqrt{G_l}\lambda}{4\pi d} \qquad (5)$$

#### *2) Two-Ray Ground Model*

The received signal in two-ray ground model consists of two components: the signal propagating through free space and the signal reflected off the ground.

The received power at distance $d$ from transmitter is

$$P_r = P_t(\frac{\lambda}{4\pi})^2\left|\frac{\sqrt{G_l}}{l} + R\frac{\sqrt{G_r}e^{-j\Delta\phi}}{x + x'}\right|^2 \qquad (6)$$

where, $G_l$ and $G_r$ are the products of antenna gains;

$l$ is the length of direct path;

$x + x'$ is the length of reflection path;

$\Delta\phi$ is the phase difference between the two received signal components (denoted by Eq.7)

$$\Delta\phi = \frac{2\pi(x + x' - l)}{\lambda} \qquad (7)$$

$R$ is the ground reflection coefficient. There are two cases in reflection including vertical polarization and horizontal polarization. In the case of vertical polarization,

$$R = \frac{\sin\theta - \sqrt{\varepsilon_r - \cos^2\theta}}{\sin\theta + \sqrt{\varepsilon_r - \cos^2\theta}} \qquad (8)$$

with $\varepsilon_r$ is the dielectric constant of the ground.

The path loss of two-ray ground model is

$$PL[dB] = -20\log_{10}\frac{\lambda}{4\pi}\left|\frac{\sqrt{G_l}}{l} + R\frac{\sqrt{G_r}e^{-j\Delta\phi}}{x+x'}\right| \quad (9)$$

### 3) *Single Knife-Edge Diffraction Model*

When there is an obstacle between T-R, the shape of the obstacle can be viewed as knife-edge for calculating the loss caused by diffraction.

The Fresnel-Kirchoff diffraction parameter $v$ is

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} \quad (10)$$

where, $h$ is the height of the top of the obstacle above the straight line joining the two ends of the path, if the height is below this line, $h$ is negative. $d_1$ and $d_2$ are the distances of the two ends of the path from the top of the obstacle. $\lambda$ is the wavelength.

When the first Fresnel zone is unobstructed ($v \le -0.78$), the effect caused by diffraction can be neglected. The approximation of the loss caused by diffraction can be expressed as a function of $v$:

$$J(v) = \begin{cases} 6.9 + 20\log_{10}(\sqrt{(v-0.1)^2+1} + v - 0.1) & v > -0.78 \\ 0 & v \le -0.78 \end{cases} \quad [dB] \quad (11)$$

### 4) *Multiple Knife-Edges Diffraction Model*

There may be several separate obstacles between T-R. If there are more than three obstacles, the effect caused by each obstacle will be evaluated, and only the larger three will be employed to calculate the loss.

Assuming the number of obstacles is $n$, the Fresnel-Kirchoff diffraction parameter $v_i$ of obstacle $i$ is

$$v_i = h_i\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_{i1}}+\frac{1}{d_{i2}}\right)} \quad (12)$$

The obstacle with the highest value of $v$ is termed as the principal edge $p$, and the corresponding loss is $J(v_p)$. If $v_p \le -0.78$, the total diffraction loss is 0; otherwise $v_p > -0.78$, the procedure is described as follows:

- Obtain the largest $v_t$ with loss $J(v_t)$ from the transmitter to point $p$;
- Obtain the largest $v_r$ with loss $J(v_r)$ from point $p$ to the receiver;
- Calculate the total diffraction loss.

The total diffraction loss is

$$J = \begin{cases} J(v_p) + T[J(v_t) + J(v_r) + C] & v_p > -0.78 \\ 0 & v_p \le -0.78 \end{cases} \quad [dB] \quad (13)$$

where,

$$T = 1.0 - \exp[-J(v_p)/6.0] \quad (14)$$

$$C = 10.0 + 0.04D \quad (15)$$

$D$ is the total path length (km).

## Vanet Channel Modeling

### *VANET Channel Analysis*

In VANET, the communication between vehicles may be interfered by other vehicles as the obstacles. If the communication is not interfered, the signal will propagate in LOS path, otherwise in NLOS path. In the condition of NLOS, the signal power attenuates significantly.

The antenna is usually installed on the roof of the vehicle. The LOS may exist even if there are other vehicles between T-R. As shown in Fig.1, the height of the obstacle is below the straight line joining the T-R antennas. As a general rule, if the first Fresnel ellipsoid is not obstructed, the effect of the diffraction can be neglected, and it can be regarded as LOS.

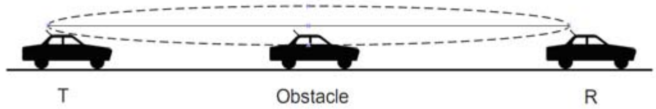


FIG.1 THE LOS EXISTS WHEN THERE IS AN OBSTACLE BETWEEN T-R

In VANET simulation, the channel model should be established in the condition of LOS and NLOS respectively. On the one hand, in the real traffic, the V2V communication is switching between LOS and NLOS constantly. It's not suitable to describe the propagation of signal and the effect of obstacles using the statistical model. On the other hand, in the specific scenario, the sizes and locations of vehicles or obstacles are available, it can be determined whether there exists LOS or not. When calculating the path loss, different models should be adopted according to whether there exists LOS or not.

When there is no vehicle between T-R, the direct component and the ground reflection component are

mainly considered. When there are one or more vehicles between T-R, it needs to determine whether there exists LOS. If LOS exists, only the direct component is considered, otherwise the diffraction loss caused by obstacles need to be considered. The effect of reflection and scattering from the surrounding objects are relatively weak, so not included in this paper.

### *LOS/NLOS Judging and Path Loss Calculation*

In specific scenarios, the information of a vehicle can be obtained at any time, including the road belonged, the coordinate of the vehicle, the size of the vehicle and the height of the antenna. The information is used to judge LOS/NLOS and calculate the path loss.

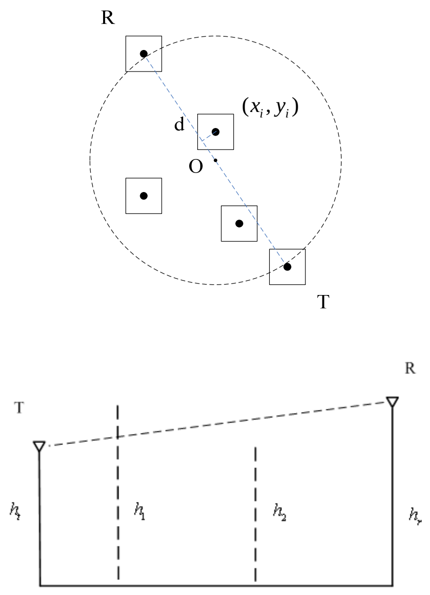


FIG.2 LOS/NLOS JUDGING WHEN THERE ARE OBSTACLES BETWEEN T-R

The coordinate of vehicle $i$ is donated as $(x_i, y_i)$, the mean value of its size is donated as $l_i$, the height of the antenna is donated as $h_i$, the distance from vehicle $i$ to the straight line joining T-R is donated as $d_i$, the middle point of the straight line joining T-R is donated as $(x_0, y_0)$, the distance between transmitter and middle point is donated as $r$, as shown in Fig.2. The procedure of LOS/NLOS judging is as follows:

Step 1. Judge whether the straight line joining T-R is obstructed by other vehicles or not. The method is: Make a circle with center at $(x_0, y_0)$ and radius equal to $r$. In the simulation scenario, find all the vehicles meet $\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} < r$ and $d_i < l_i$. If no vehicle meets the condition, go to Step 6; otherwise go to the next step.

Step 2. For the vehicles obstructing the straight line joining T-R, calculate the Fresnel-Kirchoff diffraction parameter $v_i$ according to $h_i$. When the first Fresnel ellipsoid is unobstructed ($v_i \le -0.78$), go to Step 5; when the first Fresnel ellipsoid is obstructed by only one vehicle ($v_i > -0.78$), go to Step 4; otherwise go to the next step.

Step 3. The situation is considered as NLOS. Use multiple knife-edges diffraction model to calculate the diffraction loss, and add the result to the path loss calculated by free space model.

Step 4. The situation is considered as NLOS. Use single knife-edge diffraction model to calculate the diffraction loss, and add the result to the path loss calculated by free space model.

Step 5. The situation is considered as LOS. Use free space model to calculate the path loss.

Step 6. The situation is considered as LOS. Use two-ray ground model to calculate the path loss.

### *Simulation Procedure*

For the specific transmitter and receiver (two cars in simulation scenario), the procedure of calculating path loss and received power is shown as Fig.3:

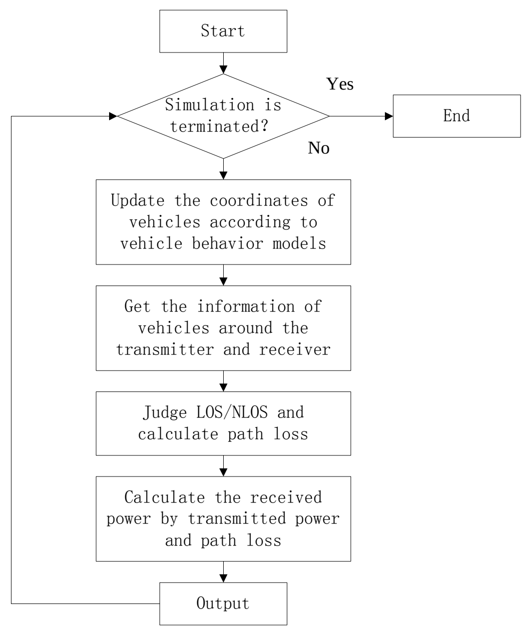


FIG.3 THE SIMULATION PROCESS DIAGRAM

The received power can be acquired by transmitted power and path loss:

$$P_r[dBm] = P_t[dBm] - PL[dB] \tag{16}$$

The received power threshold is employed to judge whether accepting the packet from transmitter. If the received power is larger than the threshold, the packet is accepted; otherwise the packet is discarded.

## Simulation Results and Discussion

### *Simulation Scenarios and Parameter Settings*

In this paper, we implement and evaluate the proposed channel model in USTCMTS2.0 platform. USTCMTS2.0 is a Service Oriented Architecture (SOA) based Microscopic Traffic Simulation (MTS) system, which was developed by DF & ITS Laboratory in USTC. This platform has been utilized to evaluate microscopic traffic models, and distributed dynamic load balancing algorithms.

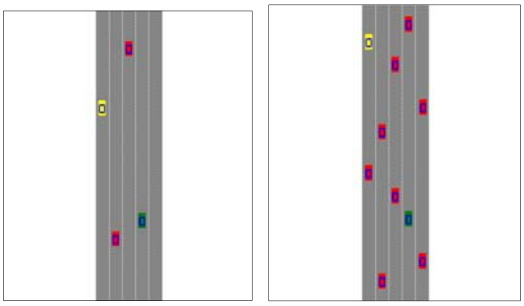

FIG.4 THE SIMULATION SCENARIOS WITH LIGHTER AND HEAVIER TRAFFIC FLOW

TABLE 1 THE PARAMETER SETTINGS IN THE SIMULATION

| Parameter | Value |
|---|---|
| Traffic flow | 500pcu/h, 3000pcu/h |
| Vehicle length | 4 m |
| Vehicle width | 2 m |
| Lane number | 5 |
| Lane width | 3.5 m |
| General vehicle antenna height | 1.4 - 1.8 m |
| Transmitter antenna height $h_t$ | 1.5 m |
| Receiver antenna height $h_r$ | 1.7 m |
| Transmitter antenna gain $G_1$ | 2 |
| Receiver antenna gain $G_2$ | 2 |
| Transmitter power $T_x - Power$ | 20 dBm |
| Received power threshold $R_x - Threshold$ | -95 dB |
| Wavelength $\lambda$ | 0.051 m |
| Dielectric constant of the ground $e_r$ | 1.02 |

In order to analyse the communication performance of VANET, we perform the simulation in two kinds of typical scenarios with lighter and heavier traffic flow respectively, as shown in Fig.4. The transmitter is marked green, the receiver is marked yellow and general vehicles are marked red. The parameter settings in simulation scenarios are listed in Table 1.

For the 5.9 GHZ carrier frequency of IEEE 802.11p, the wavelength is 0.051 m. The dielectric constant of the ground is set to 1.02. The received power threshold is set to -95 dB.

### *Switching between LOS and NLOS*

Fig.5 shows the variation of received power in the simulation of a vehicle passing through the straight line joining T-R. The received power is significantly reduced under NLOS.

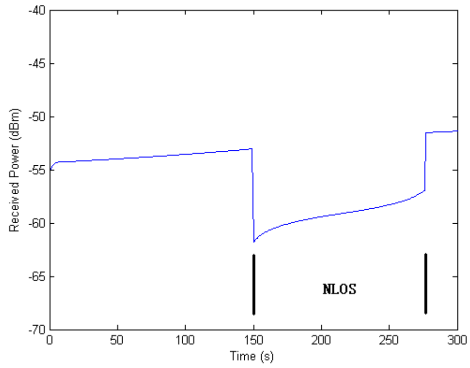


FIG.5 THE VARIATION OF RECEIVED POWER

### *Path Loss*

To evaluate the performance of proposed channel model, we collect the path loss in different T-R distance as sample points in the simulation, and then compare the statistical characteristics of sample points with real-world measurements using the LDPL model. For this purpose, the sample points are analysed by linear regression in logarithmic coordinate system.

In the scenario with light traffic flow (500pcu/h), the distribution of sample points is shown in Fig.6. The linear regression result is $n = 2.013$ and $\delta = 7.978$.

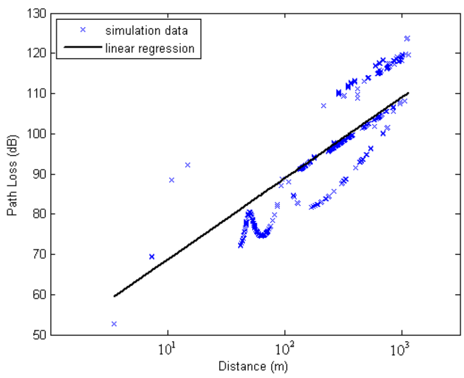


FIG.6 THE DISTRIBUTION OF SAMPLE POINTS IN LIGHT TRAFFIC FLOW SCENARIO

In the scenario with heavy traffic flow (3000pcu/h), the distribution of sample points is shown in Fig.7. The linear regression result is $n = 2.689$ and $\delta = 6.205$.

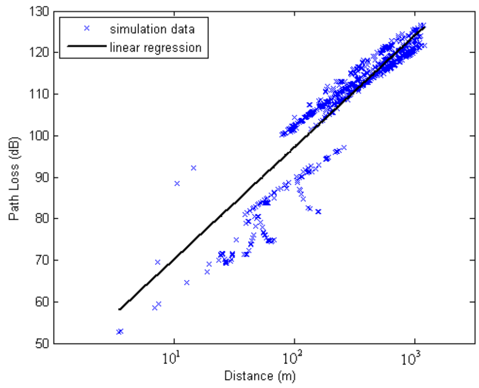


FIG.7 THE DISTRIBUTION OF SAMPLE POINTS IN HEAVY TRAFFIC FLOW SCENARIO

In several literatures, $n$ and $\delta$ in LDPL are calculated based on the real-world measurements, and the value of $n$ is between $1.5 \sim 5$, the value of $\delta$ is between $2 \sim 8$. The simulation result is consistent with the situation in reality.

### *Received Power*

In the scenario with light traffic flow (500pcu/h), the distribution of received power is shown in Fig.8.

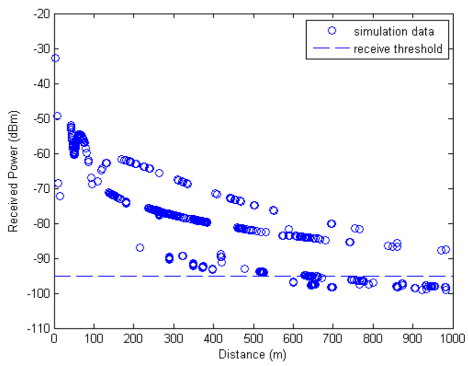


FIG.8 THE DISTRIBUTION OF RECEIVED POWER IN LIGHT TRAFFIC FLOW SCENARIO

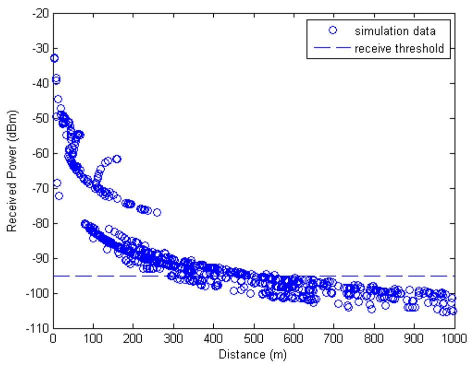


FIG.9 THE DISTRIBUTION OF RECEIVED POWER IN HEAVY TRAFFIC FLOW SCENARIO

In the scenario with heavy traffic flow (3000pcu/h), the distribution of received power is shown in Fig.9.

The simulation result shows, reliable communication distance decreases along with the traffic flow increase.

## Conclusion

In this paper, based on several typical radio wave propagation models, we developed the VANET channel model in the condition of LOS and NLOS respectively. The model proposed is more suitable than statistical model for specific scenarios in VANET simulation. We will further improve the VANET channel model by considering more factors in urban traffic environment.

## ACKNOWLEDGMENT

This work is supported financially by the Science and Technology Key Project of “12th-five-year plans” of Anhui Province (Granted No: 11010402081).

## REFERENCES

A. Goldsmith, “Wireless Communications”. New York: Cambridge Univ. Press, 2005.

Andr´ e Cardote, Filipe Neves. “A Statistical Channel Model for Realistic Simulation in VANET”. 2012 IEEE Vehicular Networking Conference (VNC).

Christoph Sommer, Stefan Joerer, Falko Dressler. “On the Applicability of Two-Ray Path Loss Models for Vehicular Network Simulation”. 2012 IEEE Vehicular Networking Conference (VNC).

Dali Wei, Feng Chen and Tongshuang Zhang. “Least Square-Support Vector Regression based Car-following Model with Sparse Sample Selection”. Proceedings of the 8th World Congress on Intelligent Control and Automation July 6-9 2010, Jinan, China.

ITU-R, "Propagation by diffraction", International Telecommunication Union, Recommendation ITU-R P.526-11, Oct.2009.

J. Maurer, T. Fugen, T. Schafer, and W. Wiesbeck. “A new inter-vehicle communications (ivc) channel model” in Proc. IEEE 60th Vehicular Technology Conference (VTC 2004-Fall), vol. 1, Sept. 2004, pp. 9–13.

J. Turkka, M. Renfors. “Path Loss Measurements for a Non-Line-of-Sight Mobile-to-Mobile Environment”. ITST 2008. 8th International Conference on ITS Telecommunications, 2008.

Kunisch.J, Pamp.J. "Wideband Car-to-Car Radio Channel Measurements and Model at 5.9 GHz". Vehicular Technology Conference, 2008. VTC 2008-Fall.

Lin Cheng, Benjamin E. Henty. "Mobile Vehicle-to-Vehicle Narrow-Band Channel Measurement and Characterization of the 5.9 GHz Dedicated Short Range Communication (DSRC) Frequency Band". IEEE Journal on Selected Areas in Communications, Vol. 25, No. 8, October 2007.

Mate Boban, Tiago T. V. Vinhoza, Michel Ferreira. "Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks". IEEE Journal On Selected Areas In Communications, Vol. 29, NO. 1, January 2011.

Maria Kihl, Kaan Bür, Fredrik Tufvesson. "Simulation Modelling and Analysis of a Realistic Radio Channel Model for V2V Communications". 2010 International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT).

Panagiotis Paschalidis, Kim Mahler. "Pathloss and Multipath Power Decay of the Wideband Car-to-Car Channel at 5.7GHz". Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd.

Scott Biddlestone, Keith Redmill. "An Integrated 802.11p WAVE DSRC and Vehicle Traffic Simulator With Experimentally Validated Urban (LOS and NLOS) Propagation Models". IEEE Transactions on Intelligent Transportation Systems, Vol. 13, No. 4, December 2012.

Thomas Mangel, Oliver Klemp. "A Validated 5.9 GHz Non-Line-Of-Sight Path-Loss and Fading Model for Inter-Vehicle Communication". 2011 11th International Conference on ITS Telecommunications.

T. S. Rappaport, "Wireless Communications": Principles and Practice, 2nd ed. Upper Saddle River, New Jersey: Prentice Hall PTR, 2009.

Xinxin Sun, Feng Chen. "An Improved Dynamic Load Balancing Algorithm for Parallel Microscopic Traffic Simulation". 2012 1ntemational Conference on Measurement, Information and Control (MIC).